

## 1.3 GHz Cryomodule (CM1) Transport Isolator Evaluation

Michael McGee (AD/MS)

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### Introduction

The 1.3 GHz Cryomodule (CM1) is scheduled for transport to New Muon Lab (NML) in mid-2008. Ten helical cable isolators (or shock absorbers) were used to protect the cavities from extreme acceleration. The isolator evaluation setup is shown in Figure 1. Benchmark maximum acceleration of 2.43 g (vertical) on base frame and 0.25 g (vertical) on any cavity was developed from earlier transport of CM1 coldmass from MP-9 to ICB on October 15<sup>th</sup>, 2007.



Figure 1. Instrumentation setup for evaluation at ICB.

### Setup and Instrumentation

The CM1 transport assembly shown in Figure 2 consists of a cryomodule weighing 16,000 lbs, a strong-back fixture weighing 5,000 lbs and (5) cross members weighing 2,100 lbs (combined). The isolation fixture includes the strong-back, cross members and connecting hardware. In total, the CM1 transport assembly weight found above isolators (not including base frame) is approximately 23,100 lbs.

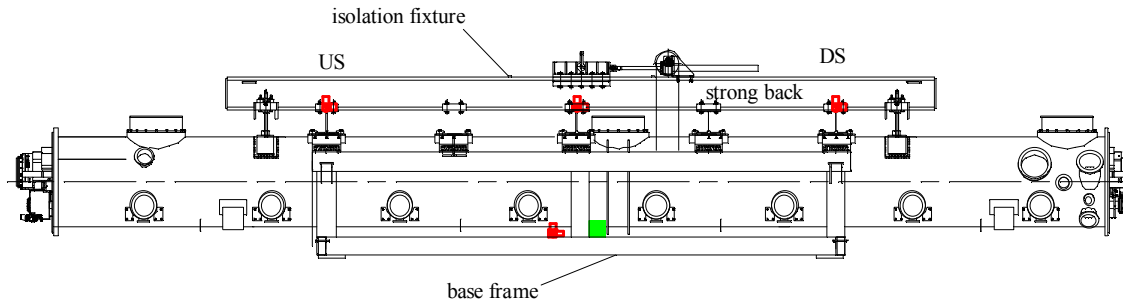
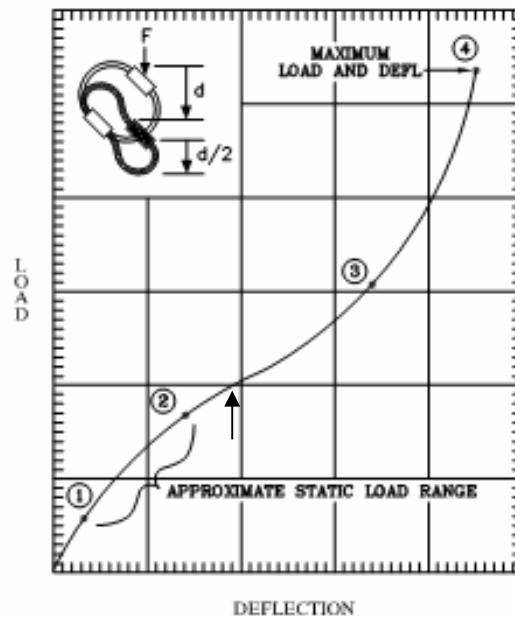


Figure 2. Elevation view of CM1 transport assembly.

Ten helical coils in a compression-roll configuration attenuate shock between the base frame and isolation fixture. The isolators, manufactured by Isolator Dynamics Corp. (IDC), part # M24A-400-08 have a static spring constant of 7,000 lb/in and dynamic constant of 3,000 lb/in. The isolator design considers a frequency ratio of 3:1, providing 80% isolation between the base frame and isolation fixture. The mid-position between points 2 and 3 in Figure 3 represents a theoretical critically damped system (where  $Q = \frac{1}{2}$ ). The CM1 transport assembly is slightly under-damped, with a load of 2,310 lbs per isolator (the position along the load/deflection curve is indicated with an arrow). This design position optimizes shock attenuation, while maintaining vibrational stability.



PART NO.	①		②		③		④		$K_v$ (VIBE) (lbs/in)	$K_s$ (SHOCK) (lbs/in)
	LOAD (lbs)	DEFL (in)	LOAD (lbs)	DEFL (in)	LOAD (lbs)	DEFL (in)	LOAD (lbs)	DEFL (in)		
M24-400-08	700	.10	1800	.25	5000	1.75	8250	2.50	7000	3000

Figure 3. Isolator data from IDC (compression/roll configuration).

In Figure 4, the center of gravity is roughly in-line with the center of the isolators (therefore maximizing stability). The downstream (DS) end of the assembly is loaded slightly more due to the relative position of strong-back fixture and cryomodule. This slight off-set was necessary in order to keep the load centered transversely and longitudinally, when lifting with a crane.

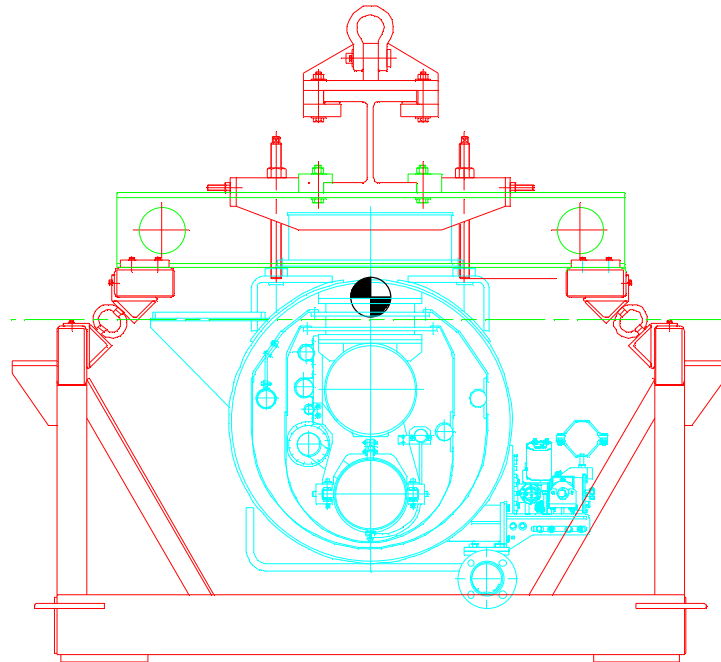


Figure 4. Center of gravity versus isolator center.

A total of (12) HS-1 geophone devices found on the isolation fixture and base frame were used for measurement. Geospace GS-14-L9 geophones were mounted just above cavities #3, #5 and #7 (one vertical and one horizontal) within CM1. Geospace GS-11-D geophones (one vertical and one horizontal) were also mounted at the upstream (US) end on the dummy quad. All geophones were connected to six National Instruments (NI) NI-9233 4-channel, 24-bit ADC modules sampled at 5KS/s, and the data was recorded to a laptop hard-drive.

## Shock Response

The shock was applied evenly with a dead-blow hammer, mid-points between instrumentation. Geophones attached on the outside (as shown in Figure 2) were asymmetric with respect to the cross-section. Therefore, shock loading was applied using the hammer on both sides and the shock attenuation factors given in Table 1 were an average between sides. Q-factors were also given in Table 1, measured by pushing CM1, suddenly in each direction.

Table 1. Summary of measured attenuation factors and Q-factors.

Direction	Base-to-fixture	Base-to-Cavity	Q-factor
x	9.2	20.8	1.57
y	10.8	21.2	2.08
z	10.4	---	2.38

## Spectral Response

Figure 5 shows the integrated Fast Fourier Transfer (fft) of a vertically driven board-band response of the base frame, isolation frame and cavities. Figures 6 and 7 depict the transversely and longitudinally driven fft plots, respectively. Table 2 provides a summary of driven responses versus a response from the air-ride trailer bed during a dry run. None of the measured natural frequencies (given in Table 2) match the excitation frequencies found on the air-ride trailer bed.

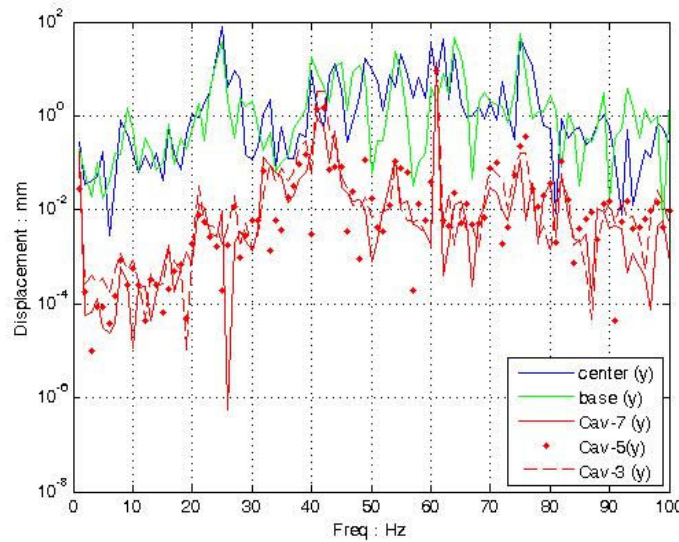


Figure 5. Vertically driven ringing test (integrated values).

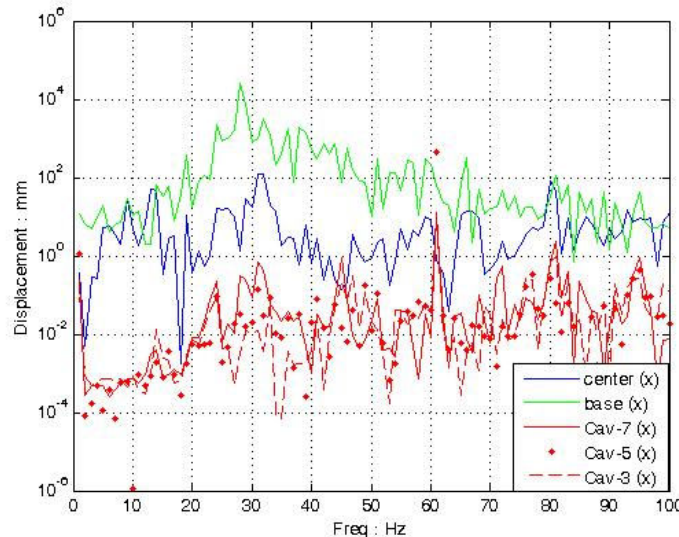


Figure 6. Transversely driven ringing test (integrated values).

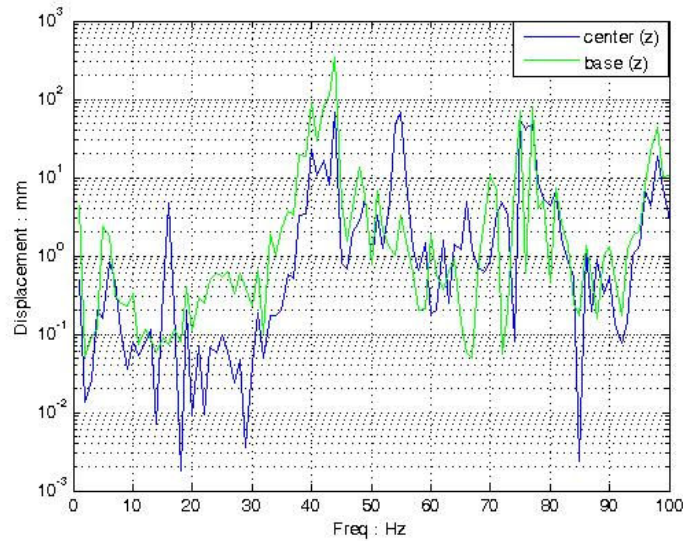


Figure 7. Longitudinally driven ringing test (integrated values).

Resonant frequencies below a natural frequency will transmit shock equally from the base frame to isolation fixture. Matching resonant frequencies will amplify shock by the Q-factors given in Table 1. Finally, resonant frequencies above will be damped by a roughly factor of 10 in each direction.

Table 1. Summary of CM1 natural frequencies versus excitation frequencies from trailer.

Direction	Ringing (Hz)	Dry Run (Hz)
z		< 4
x	5	
y & x	9	
x, y & z		10.8
x		21
y	25	
x & z		27
x	31	
x, y & z	37	
y & z	40	
y & z	45	

## Summary

During the evaluation, shock was attenuated by a factor of 10.8 vertically, 9.2 transversely and 10.4 longitudinally between the base frame and isolation fixture. Subsequently, the cavities experienced even less shock due to the connection between the isolation fixture and cryomodule CM1. No matches between possible excitation frequencies from the air-ride trailer and the natural frequencies of the CM1 transport assembly were found. The CM1 transport isolation system attenuates shock more than the coldmass transport system and shock loading will be identical. Therefore the maximum expected shock load during the transport of CM1 to NML is less than 0.25 g.